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Data interpretation of periodic strata loading characteristics in a mechanized powered support longwall caving face - a trend setter

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ABSTRACT

Longwall mining is one of the most acclaimed and widely used in underground method for coal extraction characterized with high production, productivity and safety potentials. The interaction of powered roof supports with the roof is the key issue in strata mechanics of longwall mining. Longwall coal extraction method though showed the potential of high outputs, never rose to the expectation in India due to factors pertaining to strata mechanics problems, poor spares management, adaptation of technology without suitability analysis and unyielding exertion ethnicity. Controlled caving of rock mass is a prerequisite pro thriving exploitation of coal deposits by longwall retreat with caving technique. Support resistance has evolved as the most promising and effective scientific tool to predict various aspects related to strata mechanics of such workings. Load density, height of caving block, distance of fractured zone ahead of the face, overhang of goaf and mechanical strength of the debris above and below the support base have been found to influence the magnitude of load on supports.

Key words: *Longwall mining, Caving behaviour, Support resistance analysis, Strata Monitoring*

1. INTRODUCTION

Principles of longwall mining have been traced back to the latter part of the 17th century to Shropshire and other counties in England, where it was described as a “totally different method of mining” called the “Shropshire method.” Many modifications in the original methods have occurred, but all longwall mining has involved extracting coal from a long wall or face. Today, longwall mining has emerged globally as the dominant mass production method and recognized as the safest, the most productive and cost effective underground method for coal extraction. According to coal statistics about 50% of total coal production in the world accounted from longwall mining technology. In India, longwall technology was introduced in 1960s and the first mechanised longwall face was introduced in 1978 in Moonidih colliery in BCCL with an objective to achieve higher production with safety. However, majority of the longwall mines in India have not become as successful as they were envisaged mainly due to inadequate assessment of geological parameters and poor understanding of aeromechanics of caving process under different geo-mining condition. A Proper and through understanding of geo-mechanics and caving process is essential for an effective longwall design. In view of this, there is a need for continuous strata monitoring in longwall panel.

2. ROLE OF SUPPORT RESISTANCE IN LONGWALL FACE

Support resistance has evolved as the most promising and effective scientific tool to predict various aspects related to strata mechanics of such workings. Load density, height of caving block, distance of fractured zone ahead of the face, overhang of goaf and mechanical strength of the debris above and below the support base have been found to influence the magnitude of load on supports. A reliable prediction of the caving behaviour of strata and support capacity requirement for longwall workings has always been a challenge for mining engineers. Strata behaviour in terms of uncontrolled roof caving and face instability, coupled with damage of face supports, has been led to a major bottleneck in large-scale adoption of longwall technology under such strata conditions. For these reasons, the prediction of caving behaviour and support requirement has been a major topic of research since the introduction of longwall faces. However, the support resistance observation of load on support and face convergence for these en masse caving cases were not representative of the actual field condition. It also indicated for requirement of further study to propose a suitable approach which could be integrated with the results of the support resistance to assess the dynamic load due to en masse caving of strata and to estimate the rapid yield valve requirement to ensure safe working of supports.

3. LONGWALL GEO-MECHANICS

The characterization and understanding of geo-mechanics of longwall strata is very important for determining support requirement and planning and design of panel layout so as to ensure safety, stability and higher productivity. The strata characteristics depend on stress distribution around a longwall face which is a function of the physical dimension of a longwall panel, strength of rock mass in a longwall panel, magnitude and direction of the in-situ stress, specification and operation of longwall face support, geology of rock strata and method of extraction. Most importantly the load exerted by hanging roof just behind the longwall face must be taken up by the Powered Supports, the barrier pillars on either sides of longwall panel and the collapsed debris behind the longwall face. In case of roof behind cutting face does not cave, the excessive load is directed in to the longwall face resulting in failure of coal face by overloading on Powered Supports. So, there is a need for continuous monitoring to evaluate the change of stress around the panel, fracture state of rock mass and interaction between the roof,

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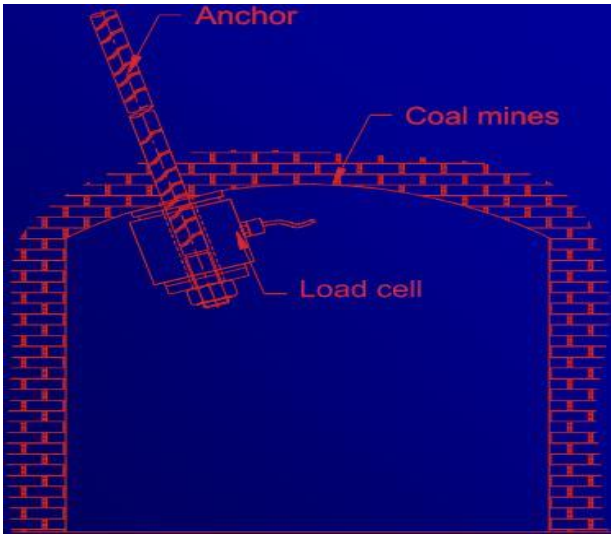

Figure 1
Vibrating Wire Type Anchor Bolt Load Cell

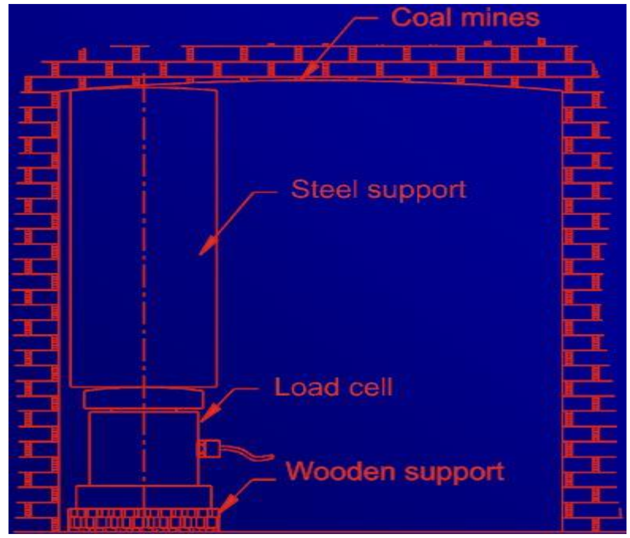

Figure 2
Vibrating Wire Type Roof Support Load Cell

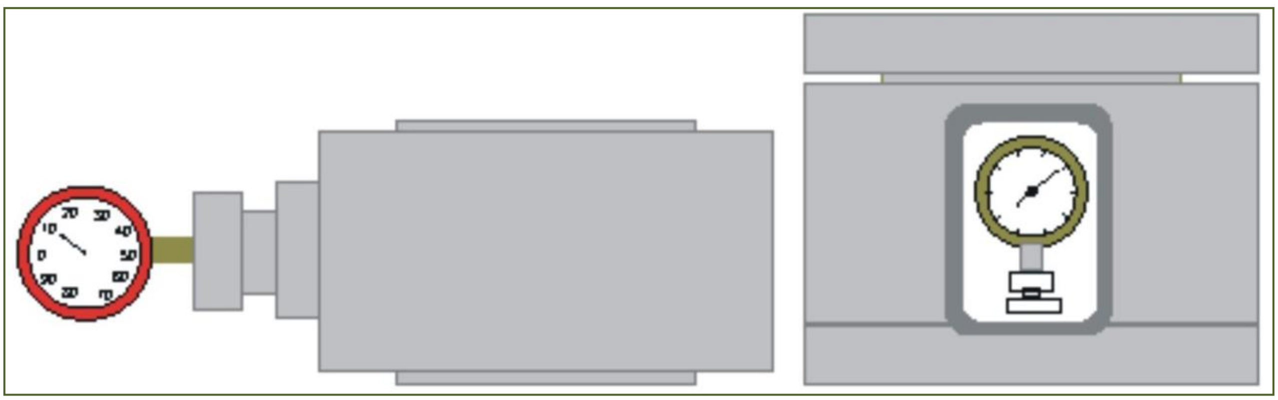

Figure 3
Mechanical Load Cell

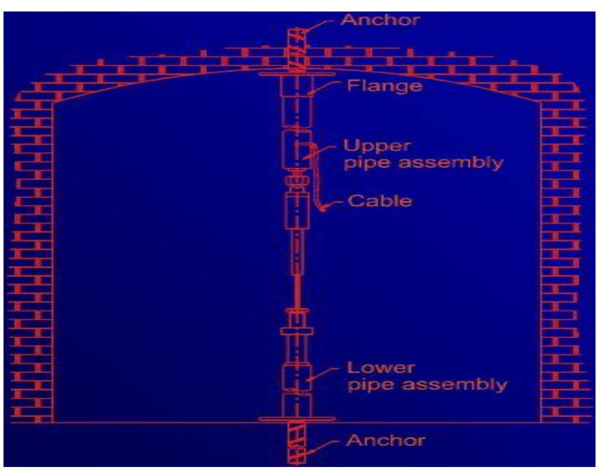

Figure 4
Remote Convergence Indicator

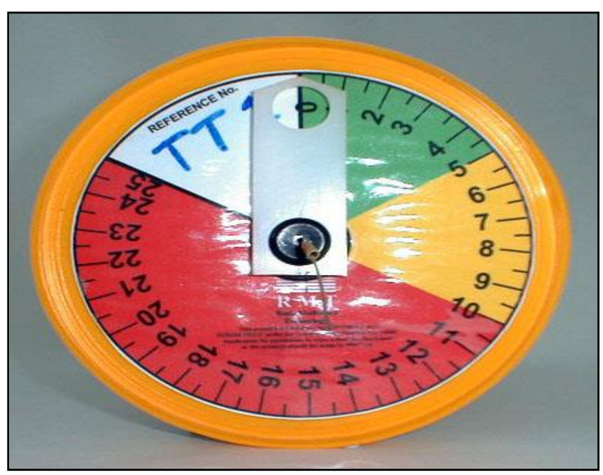

Figure 5
Rotary Tell Tale

powered support and the floor, the initiation of caving. To understand actual fracture zones, fracture propagations and failure mechanisms of the longwall face, the geo-technical field investigation with various forms of field measurements techniques have been carried out using instruments like stress capsules, extensometers, convergence measurement devices, ground subsidence surveys, borehole camera, observation of water loss in experimental boreholes etc.

4. STRATA MANAGEMENT PLAN

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It is an integrated approach for strata control monitoring with instrumentation and probabilistic approach for prevention of un-eventualities, related to ground control. It encounters with several geo-mechanical parameters and provides a basis for the design of support system to control or prevent the roof failure both safely and economically. This paper deals about Strata Management Plan and Strata Monitoring in longwall panel with strategic stress in chronologic orders.

4.1. Parameters to Be Monitored -

These may be either or all of the following.

- Bed separation and roof dilation.
- Roof Convergence
- Stress developed on pillars / longwall face
- Strain developed
- Load on supports.

4.2. Reasons for Strata Monitoring -

Monitoring of strata conditions may be carried out for a variety of reasons, including.

- Obtaining data needed for mine design, such as rock mass deformability or rock stresses.
- Verifying design data and assumption, thereby allowing calibration of computer models.
- Adjustment of mining methods to improve stability.
- Assessing the effectiveness of existing supporting system.
- Possibly directing the installation of additional support.
- Warning limit of potential strata failures.

Surface and underground inspections must be done carefully and with the assistance of high intensity inspections lights if necessary; miners, supervisors, engineers and geologists all have an important role to play in carrying out regular inspections for strata monitoring. Monitoring of strata conditions can be done either visually as given above or with the help of specialized instruments.

5. INSTRUMENTS FOR STRATA CONTROL MONITORING

There are several no of instruments are used to measure the load on roof near the excavation point in the coal mine, bed separation and convergence. Instruments are following below:

1. Load Cells
    a. Vibrating Wire type Anchor Bolt Load Cell
    b. Vibrating Wire type Roof Support Load Cell
    c. Mechanical Load Cell
2. Remote Convergence Indicator
3. Wire Type Extensometer or Tell Tale

5.1. Load Cells

Load cells are very important for measuring the tensile strength and compressive strength of the roof strata.

- These load cells are used for measuring tensile load in rock bolts, tie backs in underground cavities.
- Compressive load of coal roof /hard roof.
- To measure the compressive load at crown/ rib support in roadways.
- Some load cells are designed as three / six wire systems to nullify the eccentric loading effect. The average of three / six wire gives actual load which is more accurate.

5.1.1. Vibrating Wire Type Anchor Bolt Load Cell

Application:-

Hollow / Anchor bolt load cells are used to monitor the load in rock bolts in tunnel roof and wall (Figure 1).

- Load testing of drilled shafts.
- Load in pre-stressing and other cables.
- General compression load applications.
- In supports of underground excavation for example under vertical steel & wood posts.

Data Monitoring:-

- After installation take the initial frequency of all the three wire through readout unit and program the unit.
- Take the data in engineering unit from the three sensors.
- Add it and divide by three to get the average data.

5.1.2. Vibrating Wire Type Roof Support Load Cell

Application:-

The roof support load cells are used to measure the load of roof near the excavation point in the coal mine (Figure 2).

- These are used to monitor load under roof bed in mines and underground excavation.
- To monitor load at rib supports in roadways.
- To monitor load at crown of rib supports in tunnel.
- These are used to monitor the compression load in pile foundation.

Data Monitoring:-

- After proper vertical installation of load cell take the initial frequency reading of each wire with the help of readout unit.
- Program the readout unit as per the procedure and data asked by the readout unit.
- Measure the individual readings of each wire in tons add it and divide by three to get the average load of that load cell.

5.1.3. Mechanical Load Cell

Mechanical Load cell model SME 2570 is very suitable device for load measurement in underground (Figure 3). Few applications are given below:-

- Load testing in pre-stressing and other cables.

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Table 1
Changing of colour with the convergence in tell tale

Colour	Convergence
Green	0 - 5 mm
Yellow	5 - 10 mm
Red	10 mm+

Table 2
Necessary actions taken due to colour changes

Colour	Action
Green	No action required, continue routine monitoring
Yellow	Install additional reinforcement. Length and type of support to be determined by investigations co-ordinate by Shift In-charge / Mine Overman / Roof Control Officer
Red	Restrict access. Consult Shift In-charge/ Mine Overman / Roof Control Officer.

- Load testing in piles & drilled shafts.
- General compression load applications.
- In supports in underground excavations for example under vertical steel or wood posts.

5.2. Remote Convergence Indicator

Application:

- Convergence meter Model SME 2540 is a device for measurement of convergence in mines and underground convergence between roof and floor of the cavity (Figure 4).
- System is available with different types of sensors like linear potentiometer type displacement sensor or Vibrating wire type displacement sensor for accurate remote measurement.
- Remote type system is generally used where access is not always.

Installation:-

- The remote convergence indicator should be installed vertically by measuring the roof height where it is to be installed.
- Drill two holes of 42mm dia. of 1 feet depth in roof & floor. Grout the upper & lower pipe with flange & anchor with the help of quick setting cement.
- The installation height can be adjusted by adding /removing the pipe & adjusting the pipe length.
- Fix the sensor in between two pipes as shown in the figure by taking out sensor rod of about 80 to 90% of its capacity.

5.3. Wire Type Extensometer or Tell Tale

Telltales are safety devices which provide a continuous visual indication of the level of roof deformation that has taken place within the monitored height following installation (Figure 5). It is a very sophisticated instrument and which is very very necessary for continuous monitoring of the roof in the underground coal mines. The Rotary Telltale design has been developed to give a resolution of 1mm. This accuracy is important at sites where roof deformation levels are generally low. It should be the the responsibility of the miner each shift to record the tell tales by colour for all active areas in the section. A book should be kept at the section waiting place in which each shifts tell tale readings are recorded. Where a colour change takes place this should be reported on the Shift In-charge's statutory shift report, together with comment on any remedial actions taken. In addition the Miner records the millimeter reading of the relevant tell tales.
So, we can measure the convergence from the colour in Tell tale instrument. Colour incorporates with the convergence and actions should be taken by the officials are given below:-

Action Levels:
We can indentify convergence from the colour in rotary tell tale (Table 1).

Actions:-
From the upper table, we have to determine the convergence. Then suitable steps should be taken by the management are given in Table 2.

6. FIELD MONITORING

Strata control parameters were monitored throughout the working in the panel with the help of different electromechanical instruments.

6.1. Relation among subsidence and main fall

In Jhanjra Longwall Project after every 78m face advance mainfall happens and owing to main fall surface subsidence rate is generally 2.1m. From the following graph we can see the affiliation among surface subsidence and face advances from the goaf area (Figure 6). Here, we can see that surface subsidence increases when the extraction is more in addition the distance between the face and the goaf will be more.

6.2. Relation among roof convergence and the distance from the goaf edge

Convergence occurs owing to bed separation and riot of strata owed to void in underground coal mines. In Jhanjra longwall project rigorous subsidence happen intended for coal extraction. The following graph shows the difference of convergence between goaf area, gate road and the face (Figure 7).

6.3. Variation of mining Induced Stress with the face position

There was a sharp increase in the value of induced stress when the instrumented roof went just in bye of the goaf. Variation of induced stress over strata with advance of the face in the panel is shown in Figure 8.

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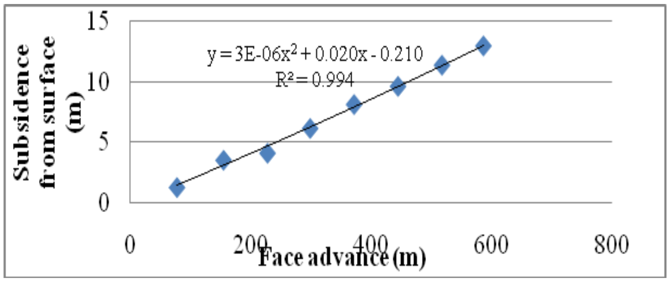

Figure 6
Variation of surface subsidence with the face position

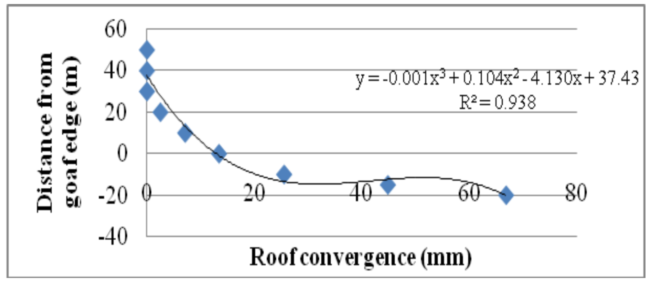

Figure 7
Convergence trend within the slice and in bye the goaf

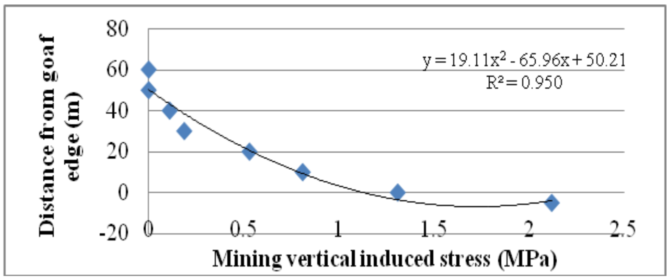

Figure 8
Variation of vertical induced stress with the face position

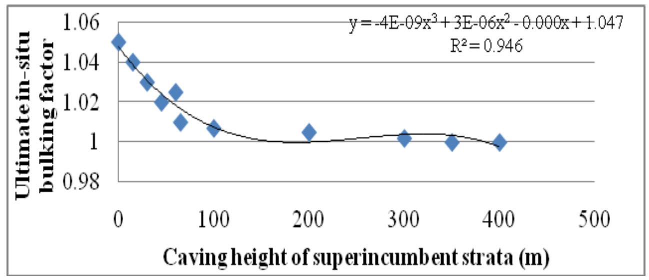

Figure 9
Change in caving height with ultimate insitu bulking factor

6.4. Variation of caving height of superincumbent strata and ultimate in-situ bulking factor

Field observations confirmed that the ultimate bulk volume falls around 45±60% of the total caving height and the remaining 40±55% caving height remains void causing surface subsidence. Based on the field study and calculation, it is found that the ultimate in situ bulking factor of coal measure strata at a longwall face is less than 1.05. The value of bulking factor starts with 1.05 and its value decreases exponentially with the increase of caving height of the superincumbent strata illustrated in Figure 9.

7. ESTIMATION OF SUPPORT RESISTANCE IN A LONGWALL FACE

CIMFR, Dhanbad has developed following formula for support resistance assessment (Prasad and Jha, 2009):-

$$P=\frac{1140}{Cm-9.6h+23-\frac{KI}{K'+1.5}} \quad (1)$$

where,
P= Support resistance required (t/m^2)
C_m= Allowable convergence (cm/m)
h= Height of extraction (m)
K= 0.025 for Indian rock condition
I= Cavability index of the bed causing the most intensive weighting

$$I=\frac{\sigma L^n}{5}t^{0.5} \quad (2)$$

where,
σ= Compressive strength of rock (kg/cm^2)
L= Average length of the core (cm)
t= Thickness of bed (m)
n= A factor, the value of which depends on the value of RQD of bed. The value of n ranges between 1 and 1.2 (RQD < 33.3 then n=1.0, RQD between 33.3 & 66.6 then n=1.1, RQD >66.6 then n=1.2)
$K^/$= A factor depending on the value of t (thickness of cavable bed) in terms of height of extraction, t up to 2, $K^/$ =2, t=2 to 4, then $K^/$=3 & 5 respectively.

8. DEVELOPMENT OF SOFTWARE TO ESTIMATE THE REQUIRED SUPPORT RESISTANCE

Support resistance is the focal constraint to design powered support. It's incredibly easy to estimate support resistance by using software. Convergence measurement and Cavality index determination is a significant task. We can estimate support resistance by flow chart (Figure 10).

For the support resistance calculation data's are collected from a longwall Project mine are given below:-

Convergence (mm)	: 61
Height of extraction (m)	: 2.9
Compressive strength of Rock (kg/cm^2)	: 718
Average length of core (cm)	: 15
Thickness of the bed (m)	: 4.8

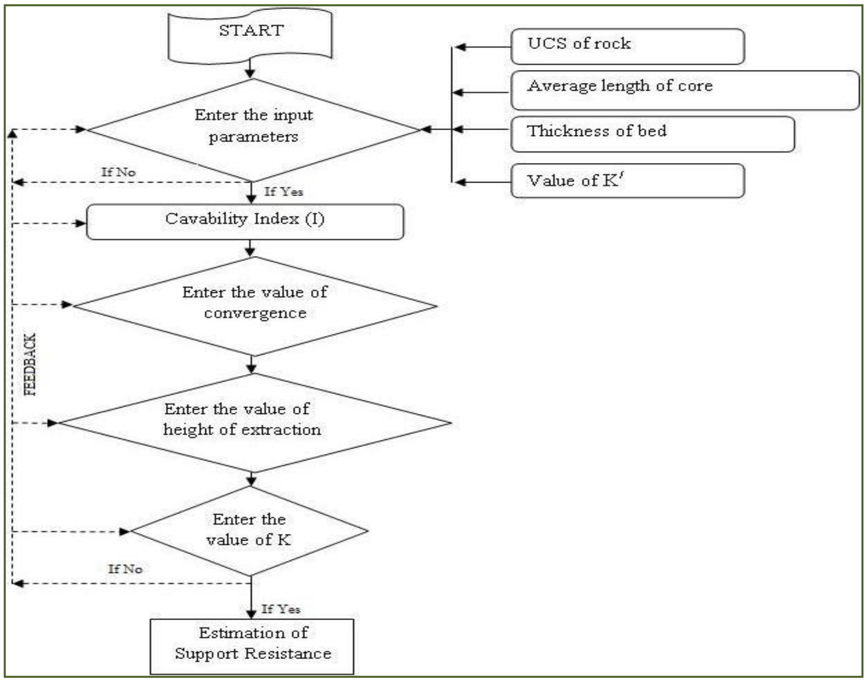

Figure 10
Flow chart algorithm for support resistance estimation

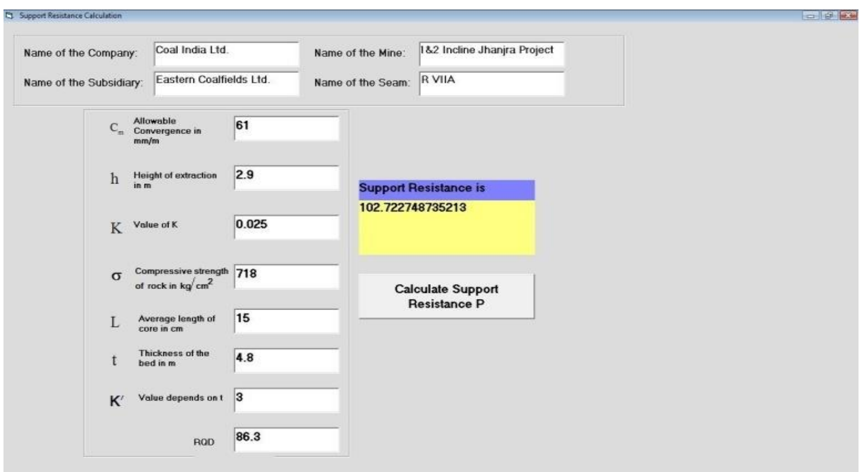

Figure 11
Estimation of support resistance by software (By Visual Basic Language)

We can find the support resistance in longwall mining (Figure 11) by the following software which has been made by C programming and Visual Basic Language:-

```
#include<stdio.h>
#include<math.h>
int main(void)
{
double i,s,l,n,t,k,kp,h,Cm,p;
printf("Enter value of sigma:");
scanf("%lf",&s);
printf("Enter value of L:");
scanf("%lf",&l);
printf("Enter value of n:");
scanf("%lf",&n);
printf("Enter value of t:");
scanf("%lf",&t);
i=(s/5.0)*(pow(l,n)*pow(t,0.5));
printf("Enter value of Cm:");
scanf("%lf",&Cm);
printf("Enter value of h:");
scanf("%lf",&h);
printf("Enter value of K:");
scanf("%lf",&k);
printf("Enter value of K':");
scanf("%lf",&kp);
p=1440.0/(Cm-(9.6*h)-(((k*i)-23)/(kp-1.5)));
printf("P=%lf\n",p);
return 0;
}
```

So, the required support resistance is 102.72 t/m^2. From this software we can understand the roof characteristics of longwall mine and required powered support capacity in the longwall face.

9. CONCLUSION

The main findings of this study are the total convergence, during the first use of a roadway as a main gate, depends on the time, the distance from the longwall face, the loading region, the support type and pattern, and the static and dynamic support loads. Future of the nation is largely dependent on success and growth of underground coal mine in the context of healthy socio economic and energy sufficiency. Safety in underground mines dictates the awareness amongst the technocrats for basic rock mechanics and practicing strata control monitoring. So proper analysis of strata control monitoring is the back bone for success of longwall mining technology.

ACKNOWLWDGEMENT

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